

LA-UR-21-22965

Approved for public release; distribution is unlimited.

Title:	Skyrmion Spin Ice in Liquid Crystals
Author(s):	Duzgun, Ayhan Nisoli, Cristiano
Intended for:	Online Artificial Spin Ice Sessions 2021, 2021-03-29 (Online, New Mexico, United States)
Issued:	2021-03-29

Disclaimer:

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by Triad National Security, LLC for the National Nuclear Security Administration of U.S. Department of Energy under contract 89233218CNA000001. By approving this article, the publisher recognizes that the U.S. Government retains nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

Skyrmion Spin Ice in Liquid Crystals

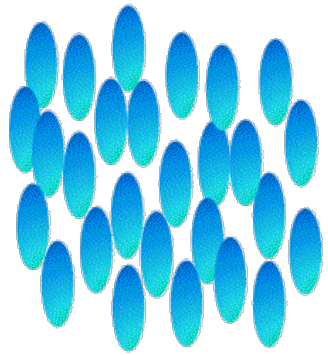
Ayhan Duzgun and Cristiano Nisoli

Los Alamos National Laboratory

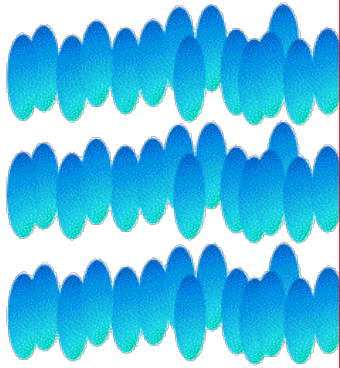
Theoretical Division



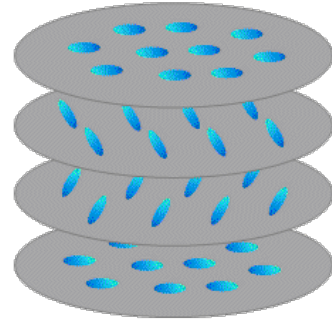
Various phases of Liquid Crystals



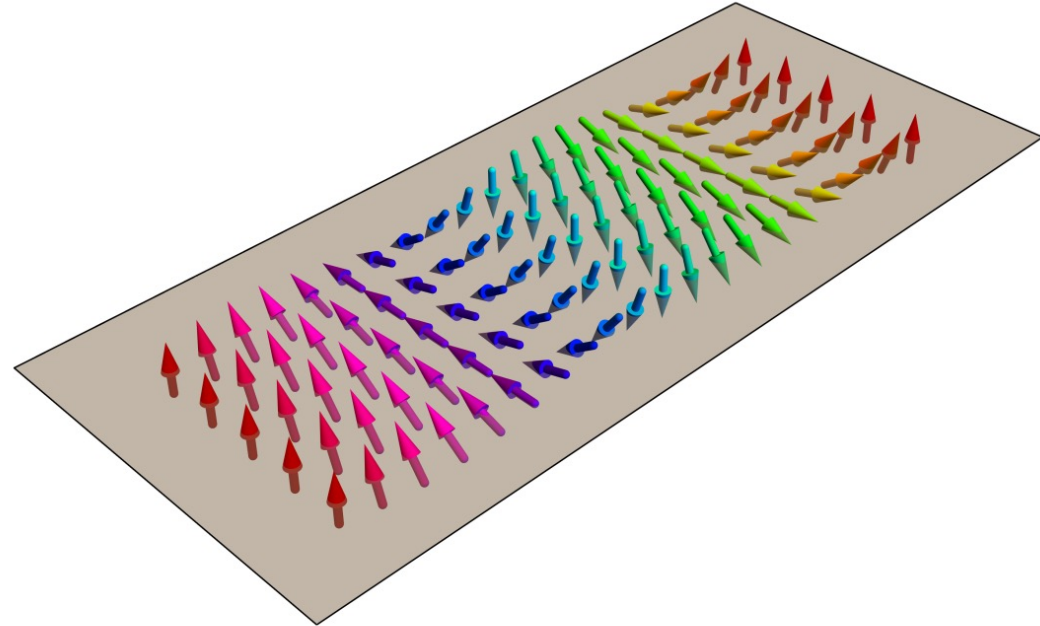
Nematic Phase



Smectic Phase

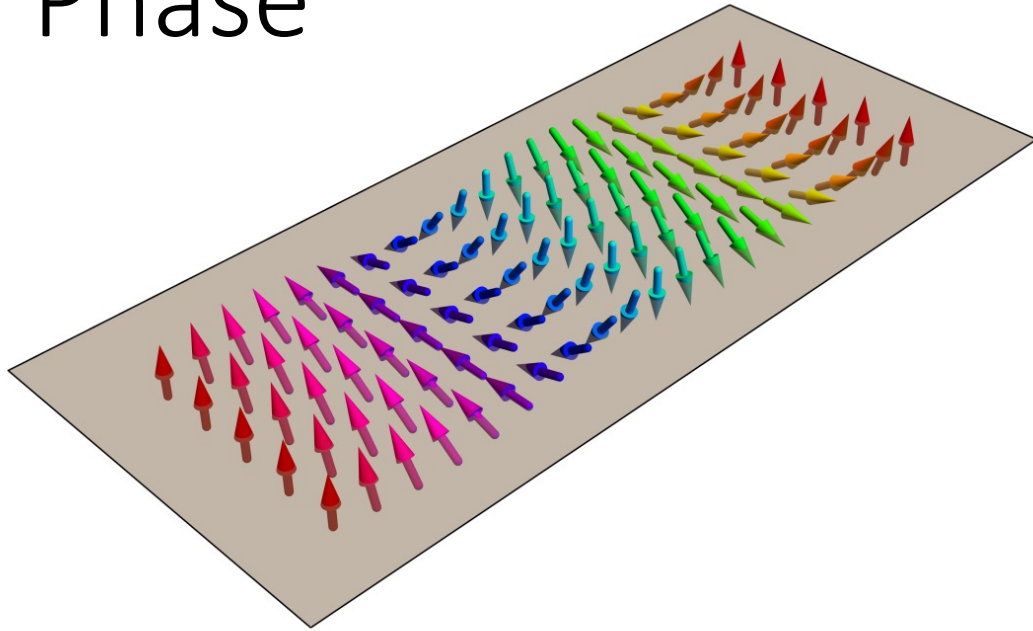


Cholesteric Phase
(Chiral Nematic Phase)

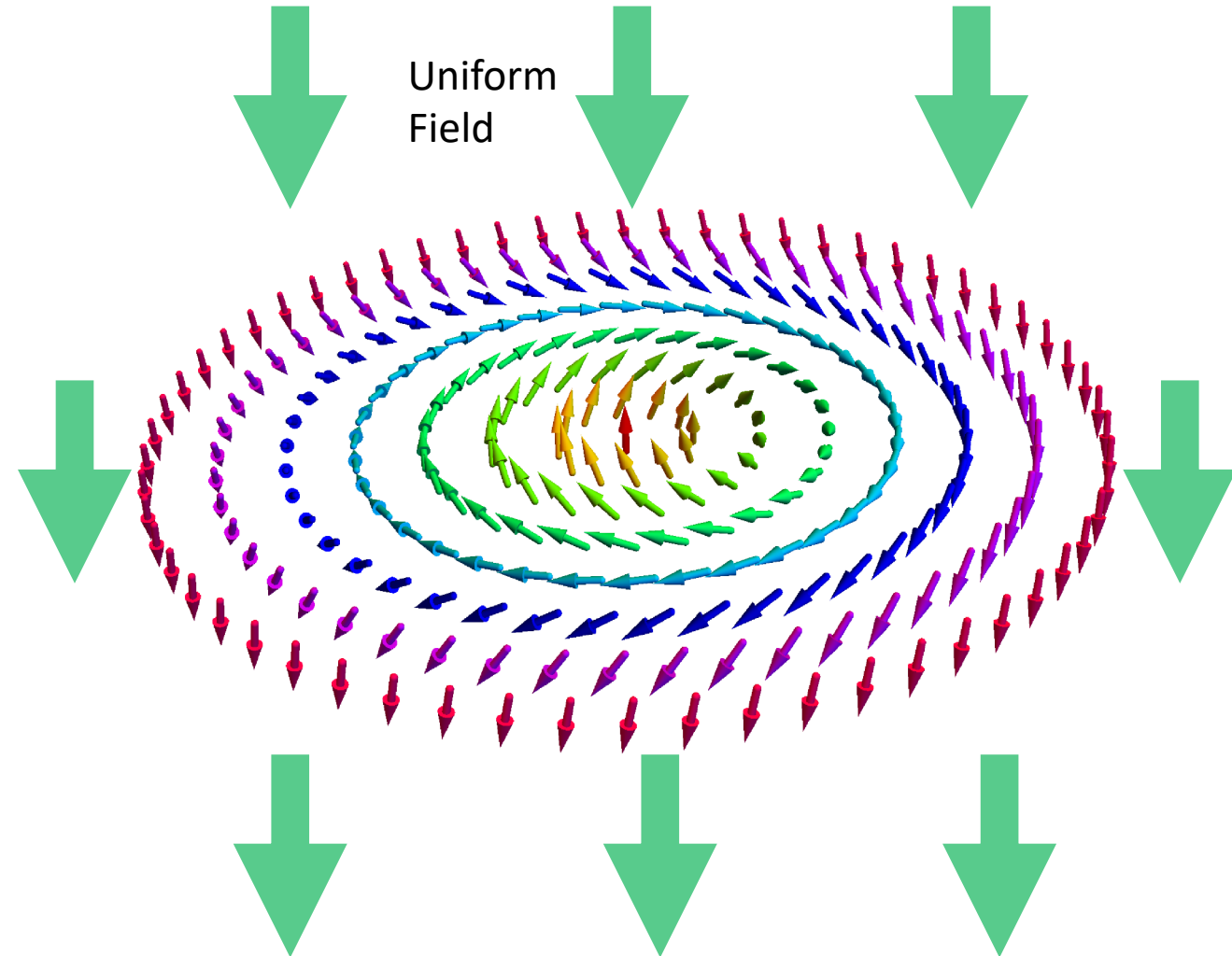


Skymion stabilized by homeotropic alignment

Cholesteric Phase



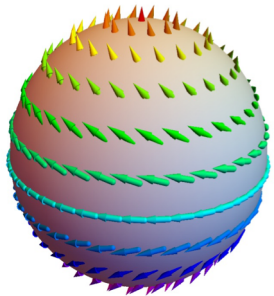
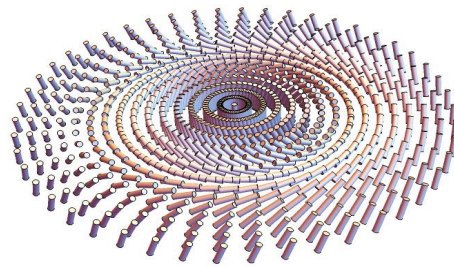
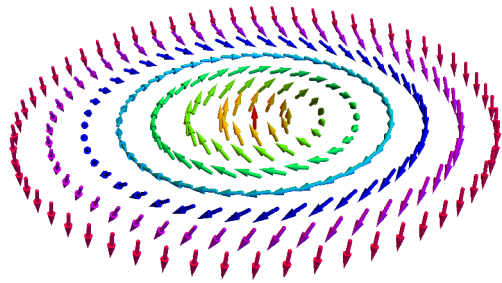
Liquid Crystal Skymion



Liquid crystal skyrmions

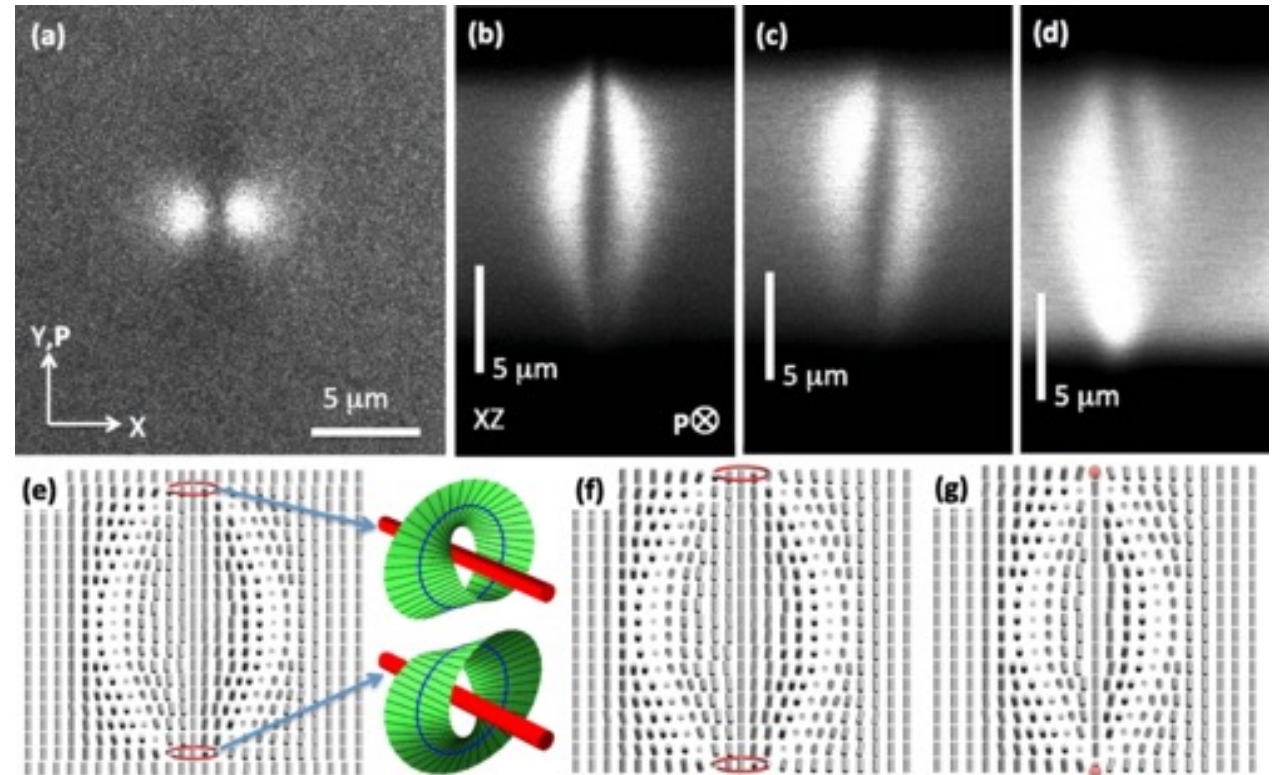
Vectorized

LC



charge
 $Q=1$

Experimental Realization



Ackerman et al.

Theoretical Model and simulations

$$F = \frac{1}{2} a \text{Tr}[Q^2] + \frac{1}{3} b \text{Tr}[Q^3] + \frac{1}{4} c \text{Tr}[Q^2]^2$$

a,b,c: Thermal coefficients

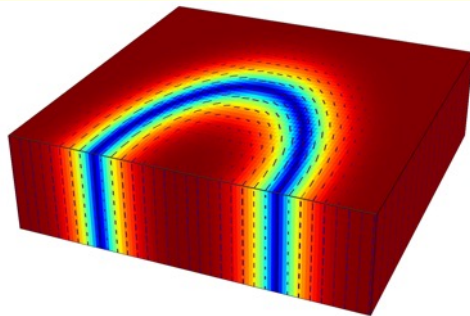
$$+ \frac{1}{2} L (\partial_k Q_{ij}) (\partial_k Q_{ij}) + 2q_0 L \epsilon_{lik} Q_{lj} \partial_k Q_{ij}$$

L: elastic constant **q₀:** natural twist

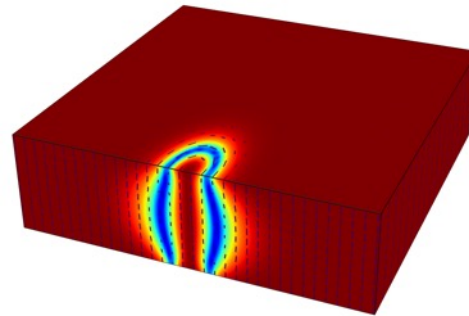
$$- \underbrace{\Delta \epsilon E^2}_{\alpha} Q_{zz} - K Q_{zz}$$

$\Delta \epsilon E^2$: dielectric anisotropy and electric field

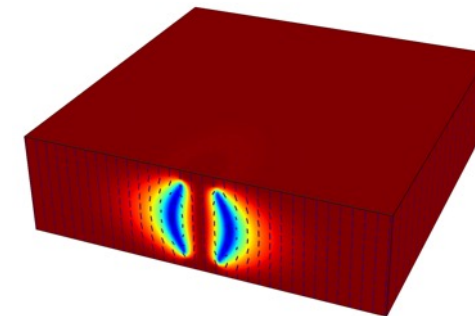
K : vertical surface anchoring strength



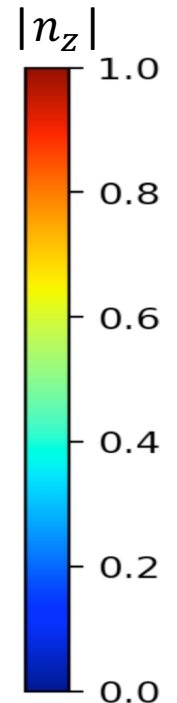
K=0, $\alpha = 0.4$



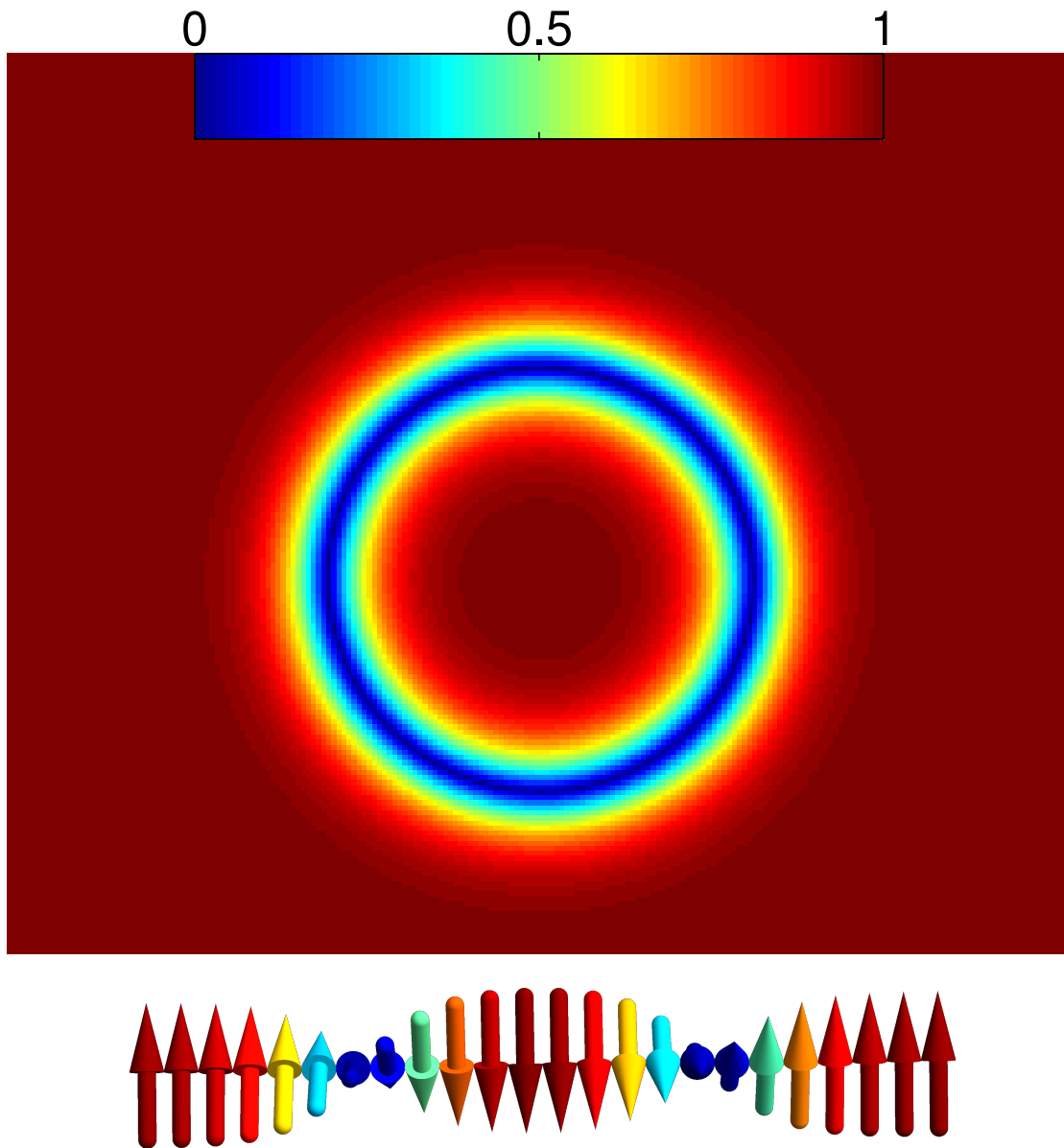
K=8.5, $\alpha = 0.2$



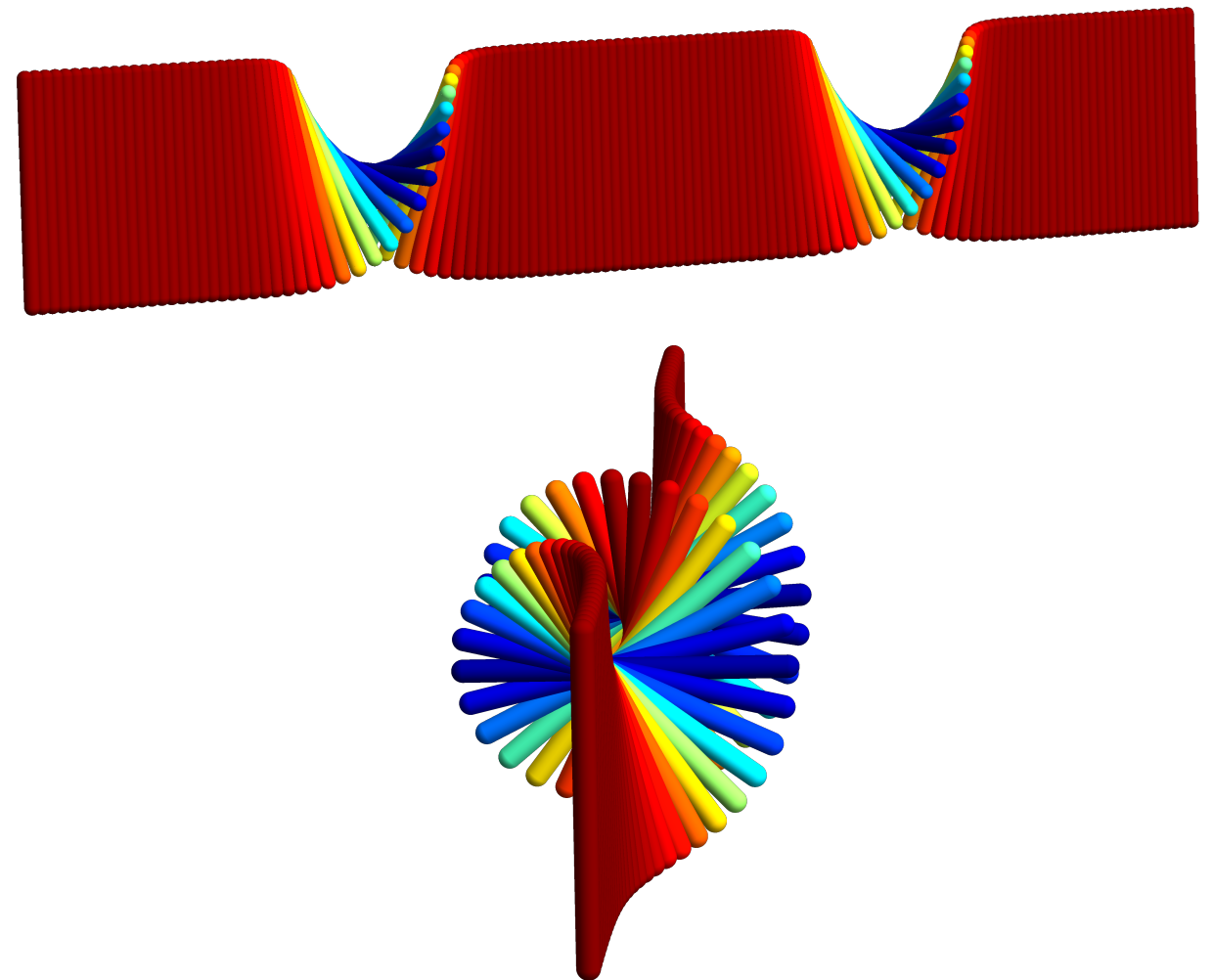
K=16, $\alpha = 0$



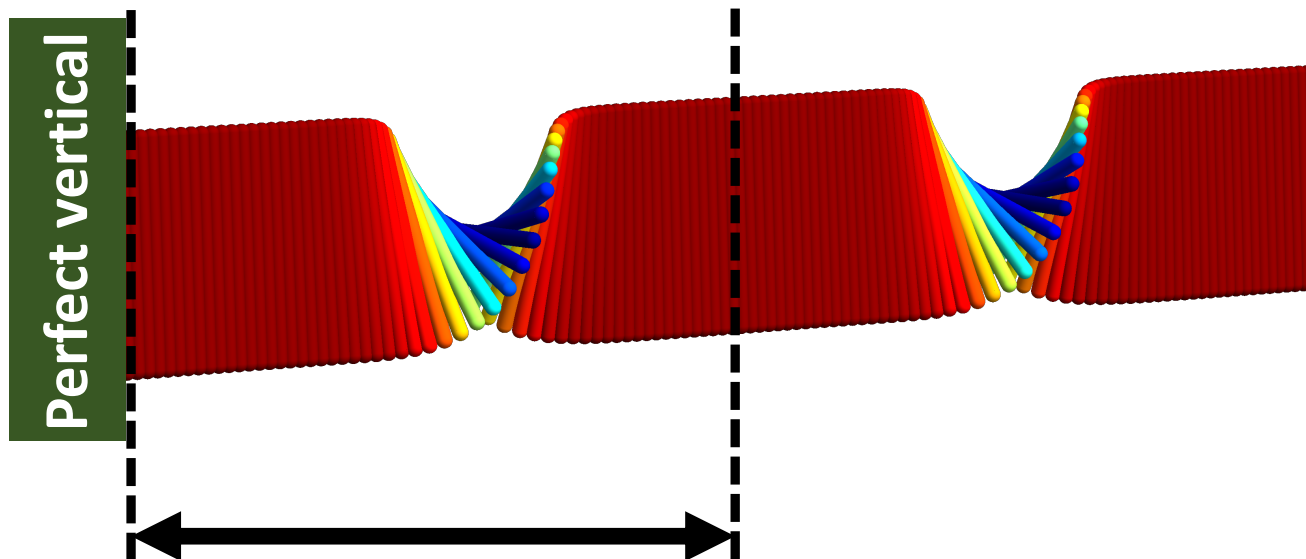
2D skyrmion



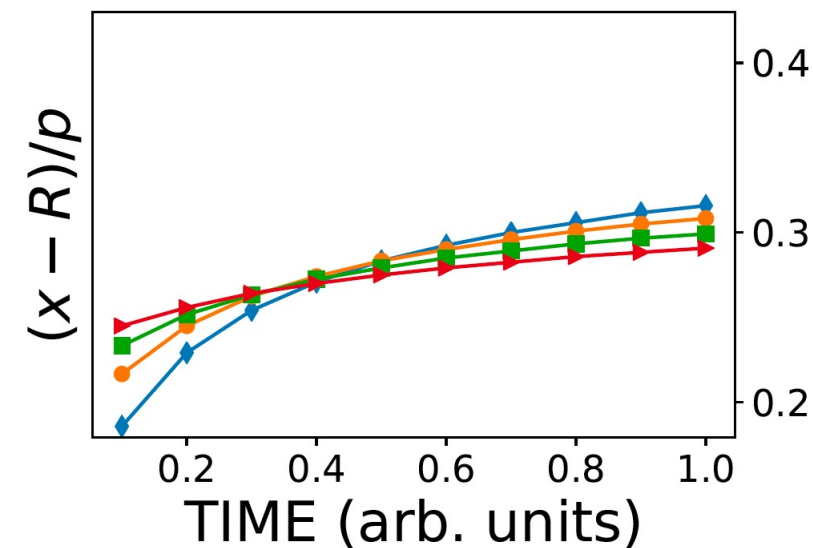
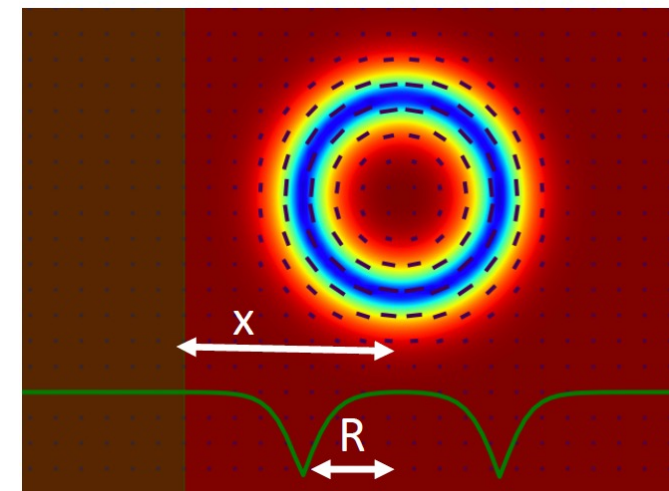
Director profile
along diameter



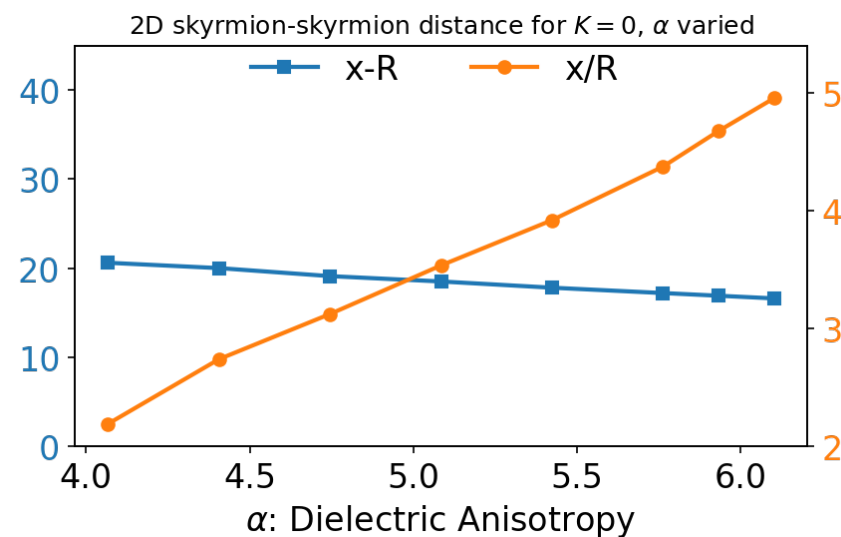
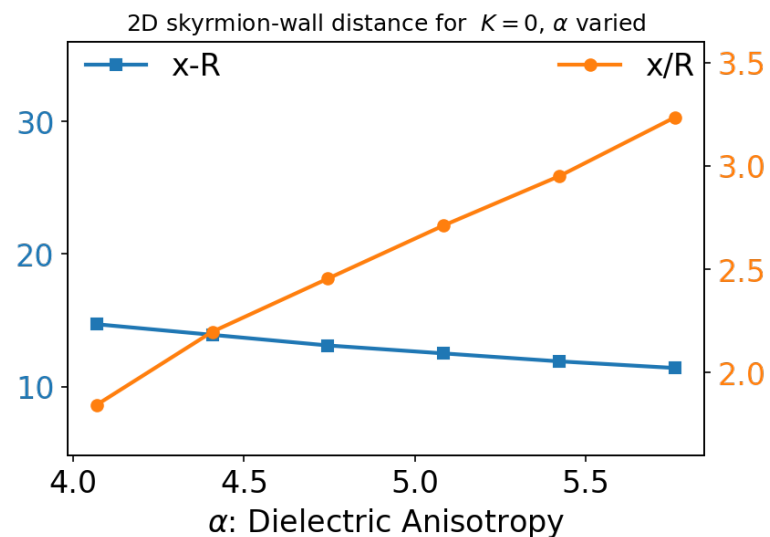
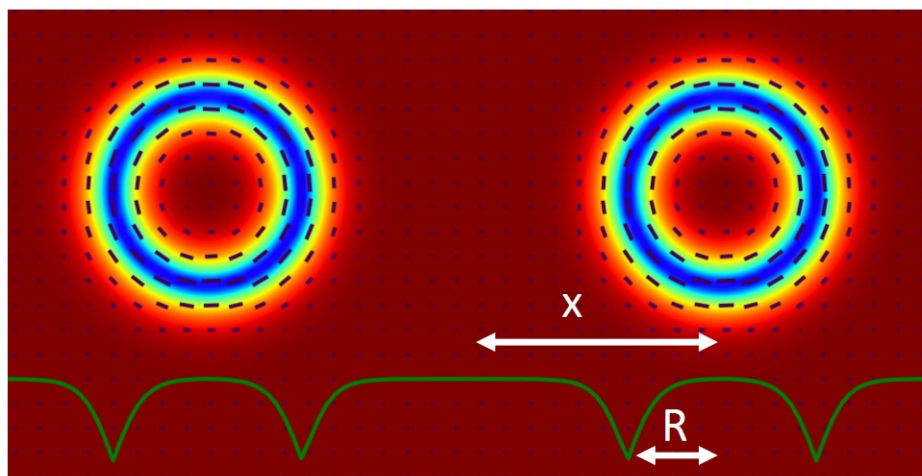
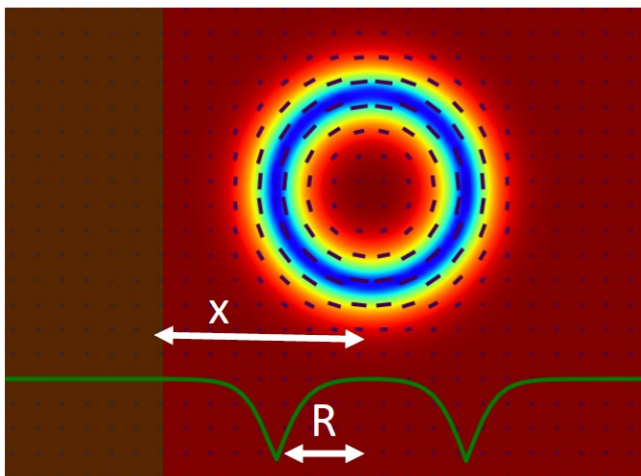
Walls produced by strong alignment



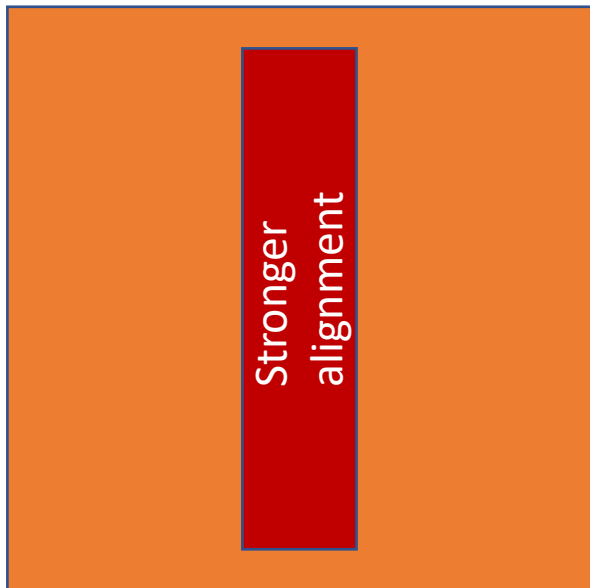
Characteristic
Relaxation length
 180° rotation



Skyrmion-skyrmion and skyrmion-wall distance



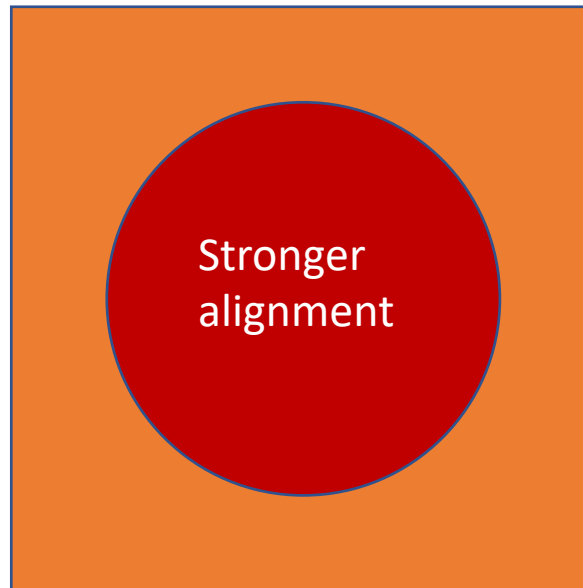
Walls, repulsive sites, attractive sites...



Wall

Stronger

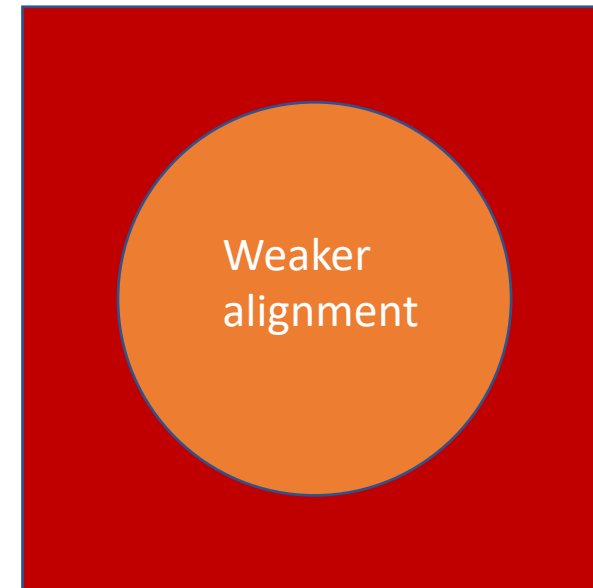
- Light
- Field
- Anchoring



Repulsive site

Stronger

- Light
- Field
- Anchoring



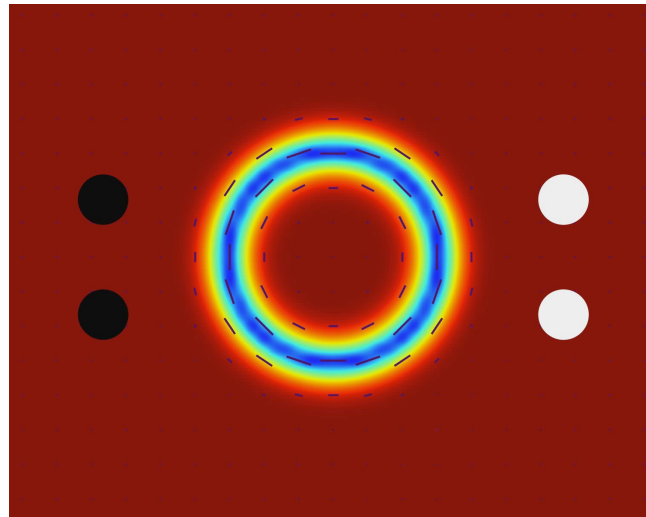
Attractive site

Weaker

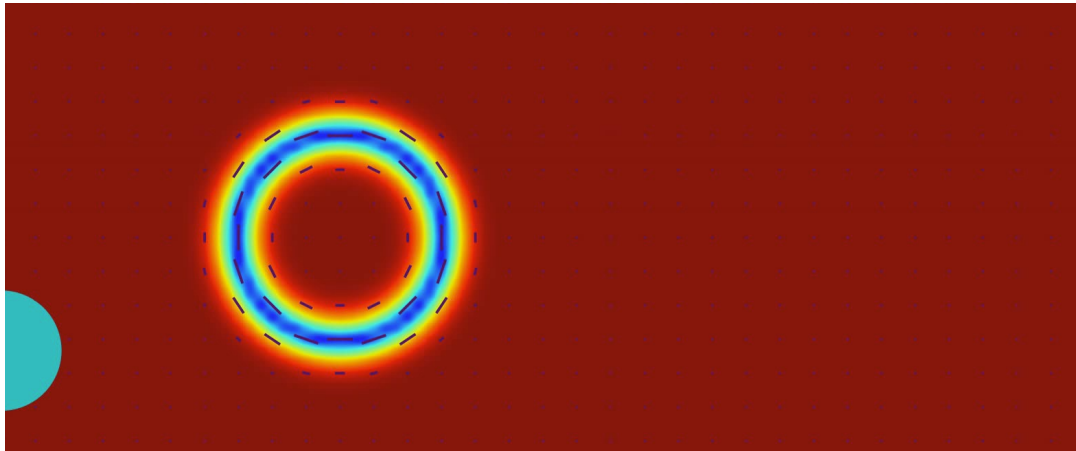
- Light
- Field
- Anchoring

Some ways to generate repulsive and attractive regions

● Strong Anchoring ○ Weak Anchoring

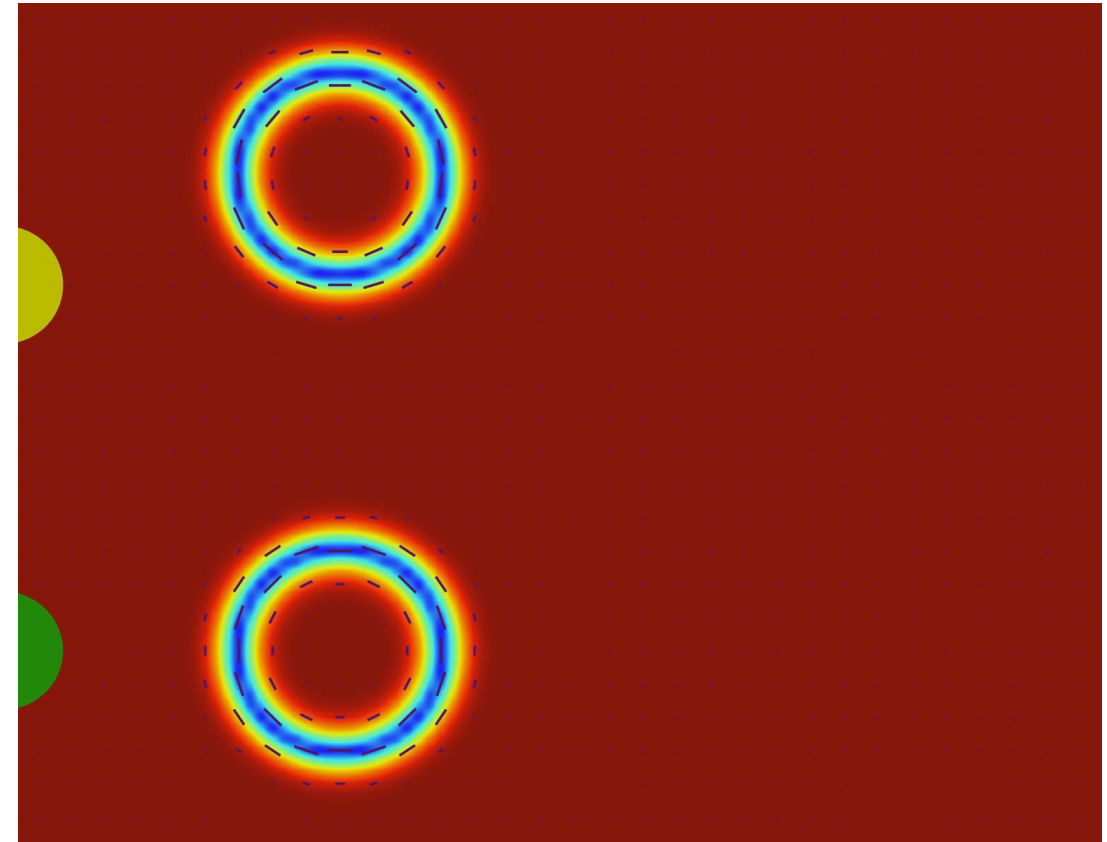


● Light



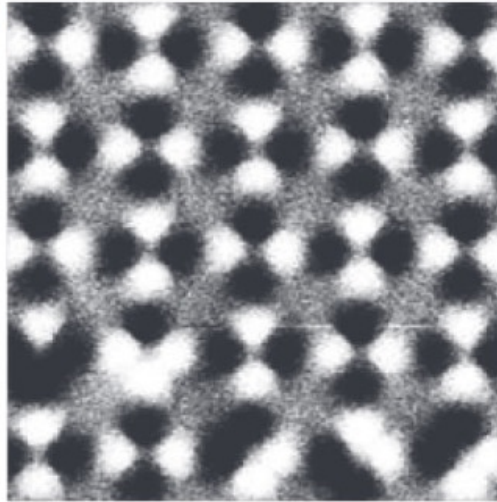
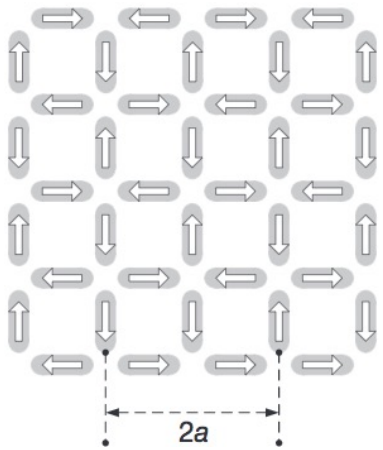
● Cancelling Field

● Strong Extra Field



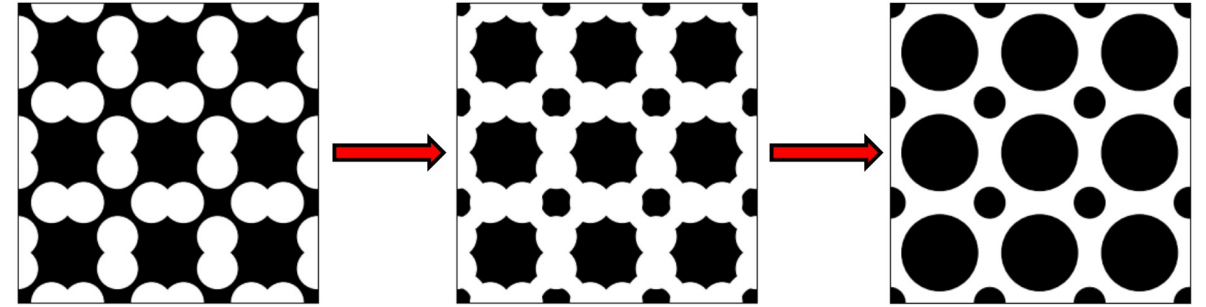
Binary traps for skyrmions

ARTIFICIAL SPIN ICE

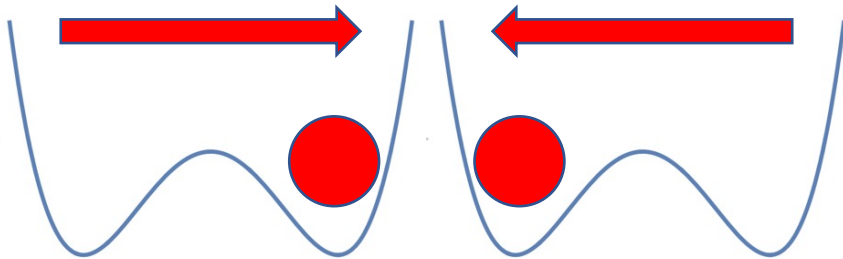


Sheng Zhang et. al.
Nature 500, p.
553–557

TRAP DESIGN

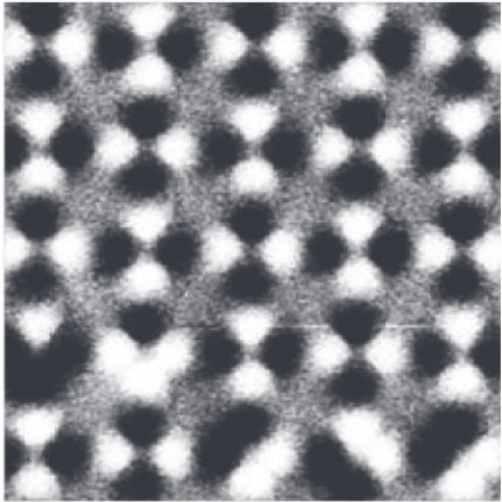
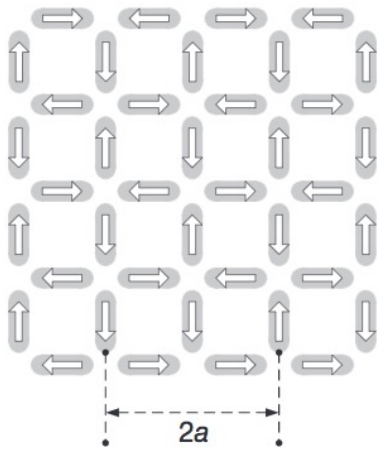


PARTICLE ICE



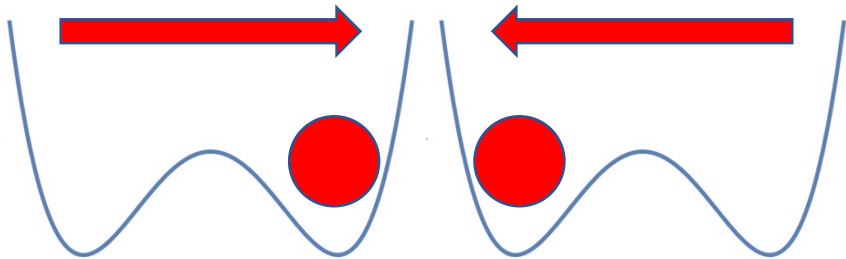
Binary traps for skyrmions

ARTIFICIAL SPIN ICE

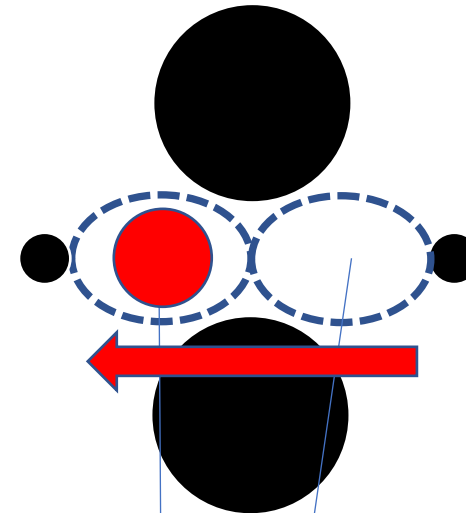
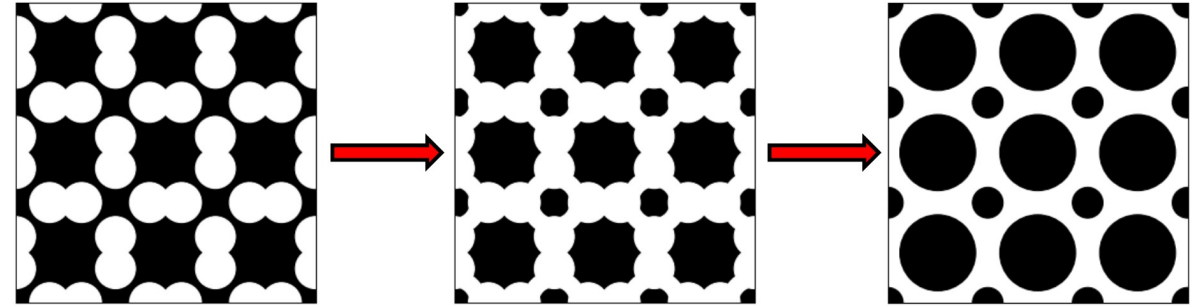


Sheng Zhang et. al.
Nature 500, p.
553–557

PARTICLE ICE



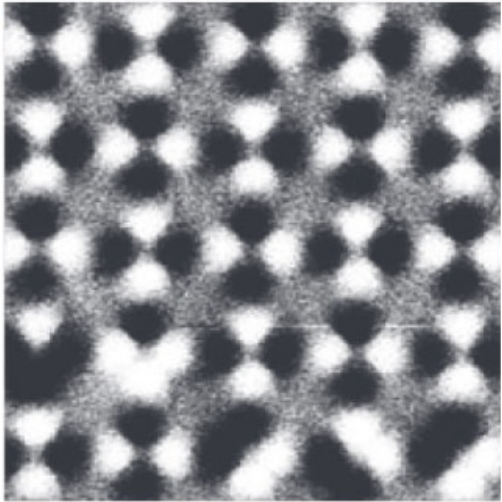
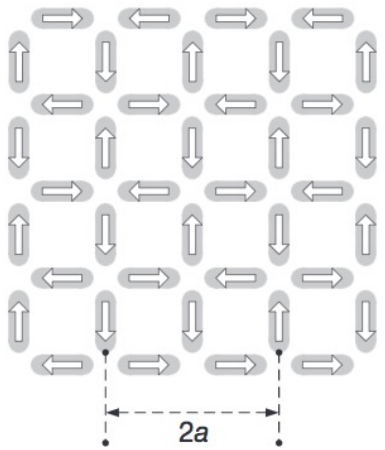
TRAP DESIGN



Binary trap

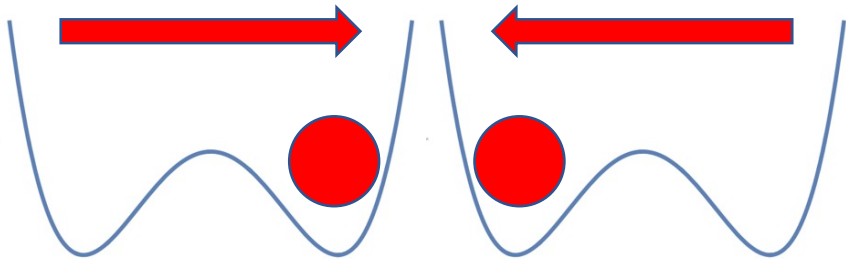
Binary traps for skyrmions

ARTIFICIAL SPIN ICE

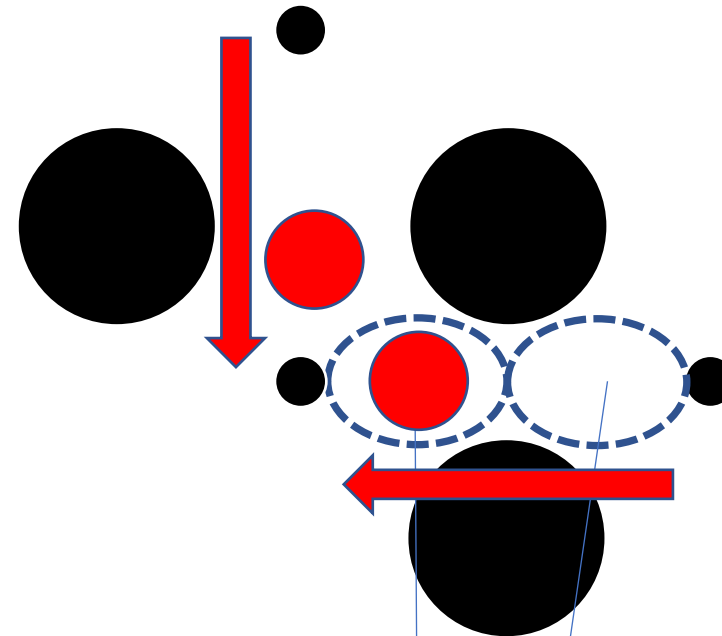
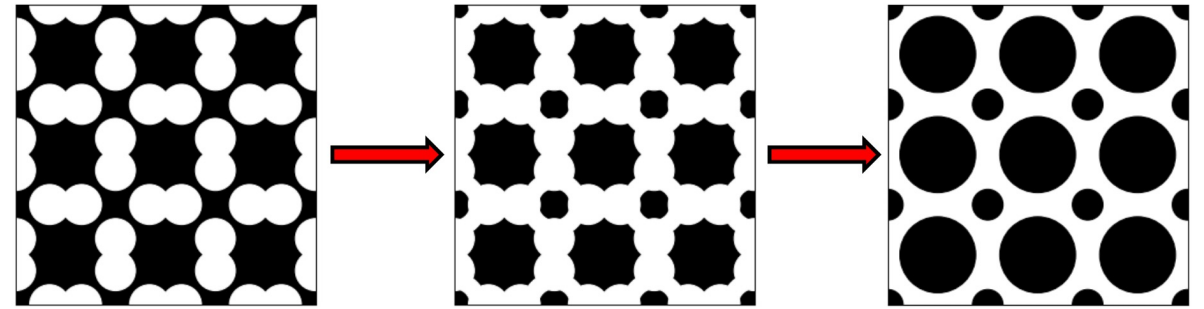


Sheng Zhang et. al.
Nature 500, p.
553–557

PARTICLE ICE

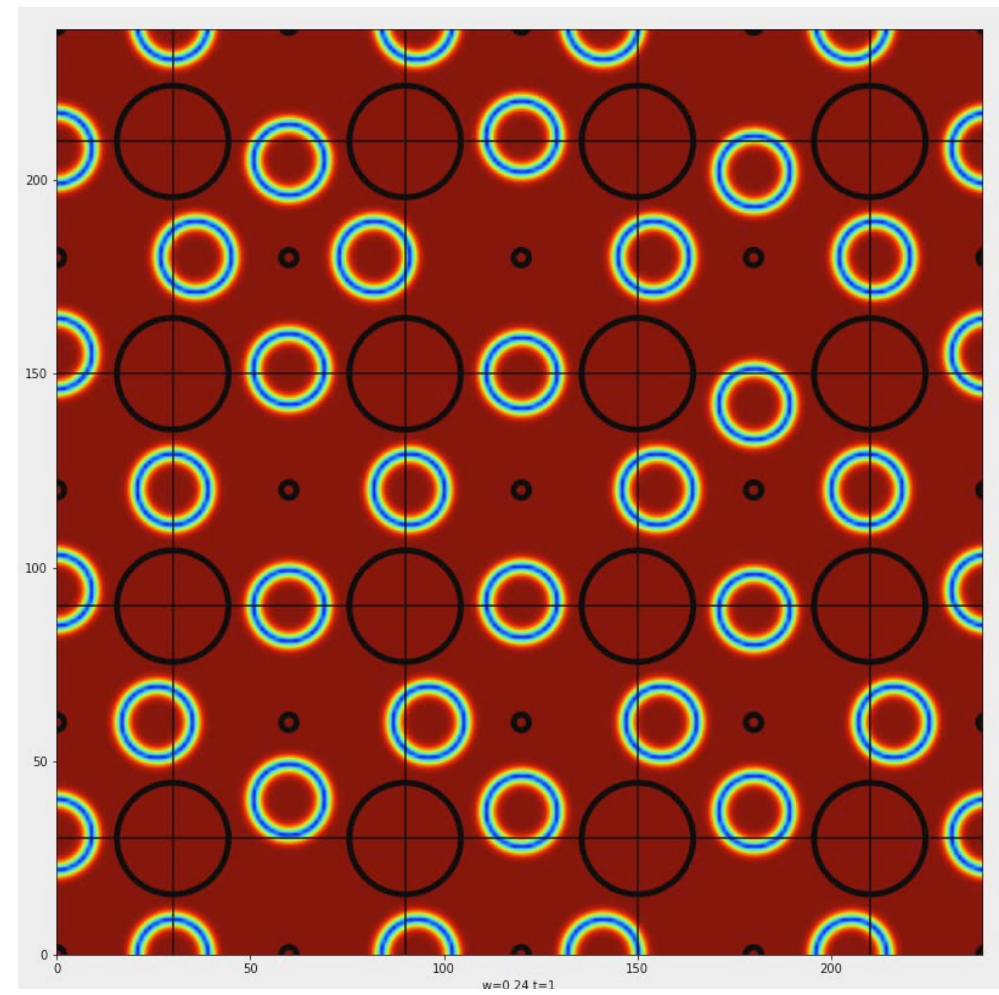
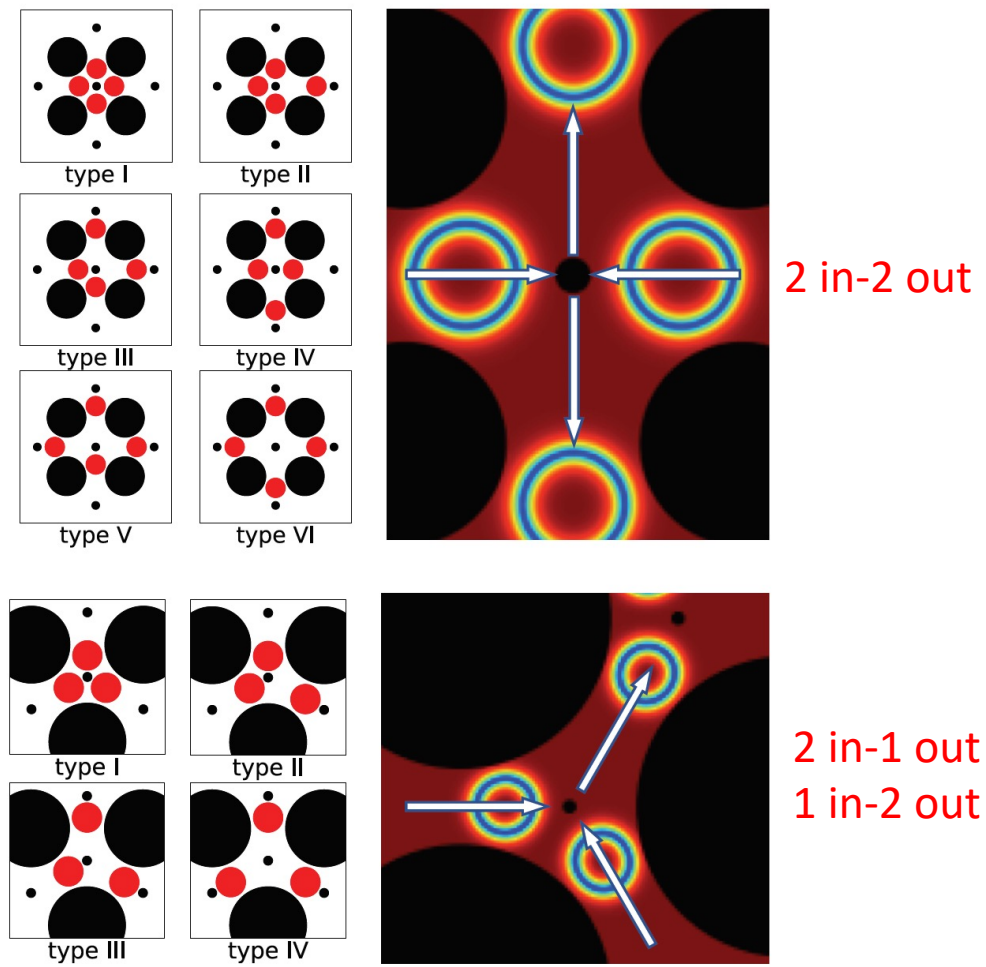


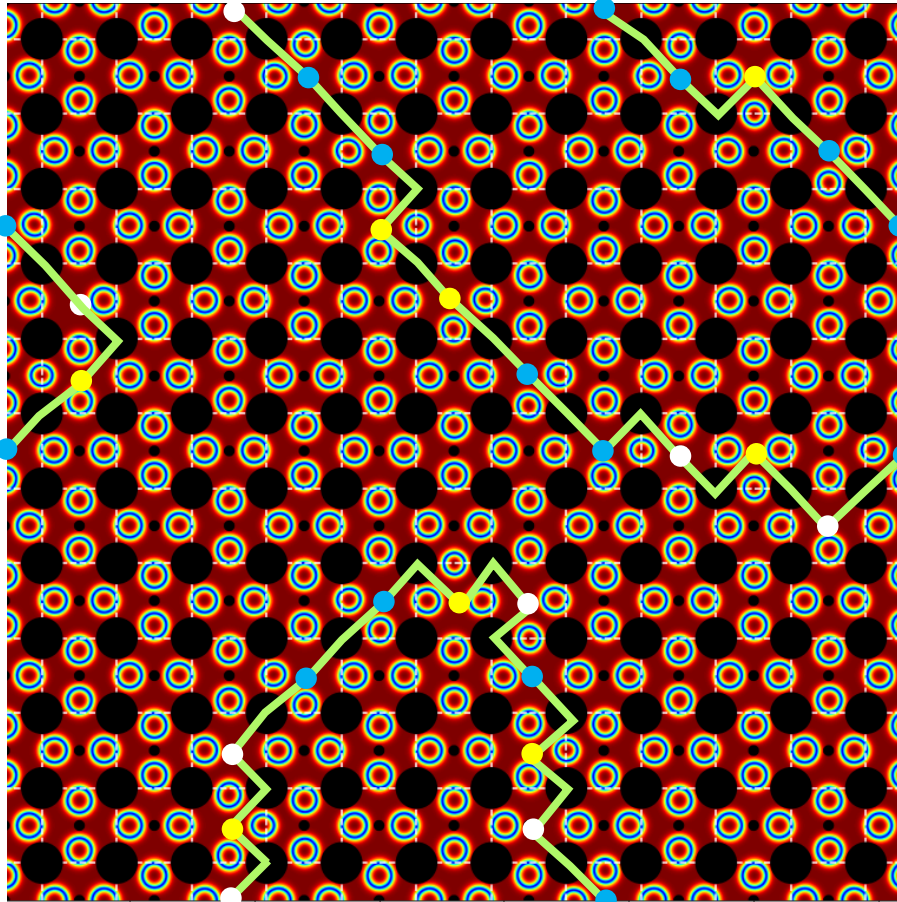
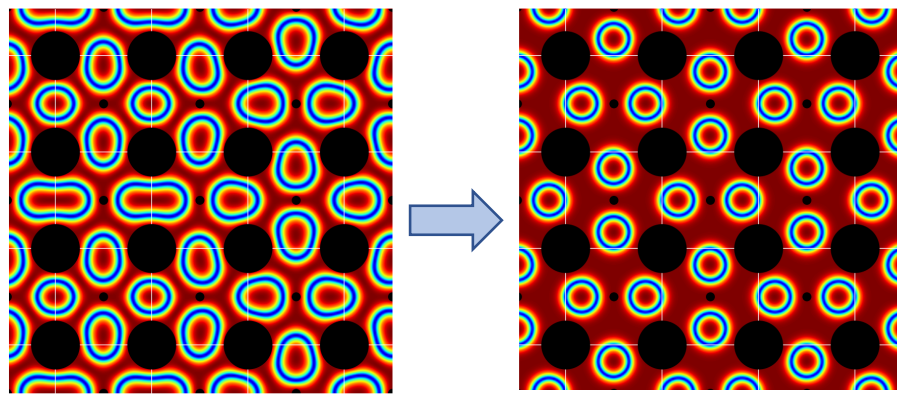
TRAP DESIGN



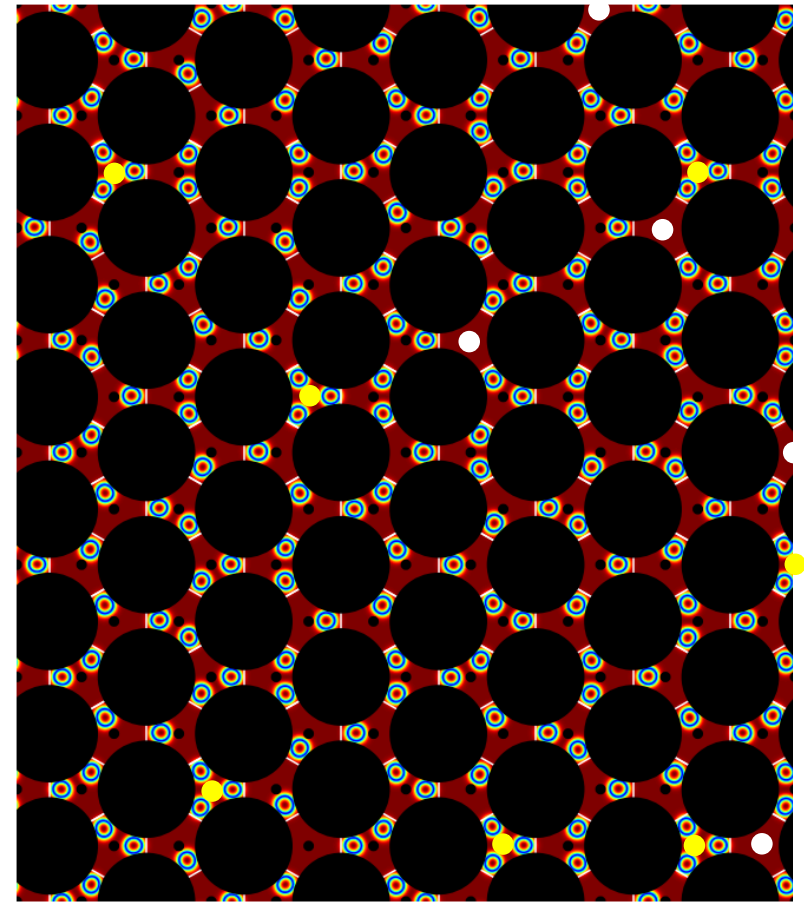
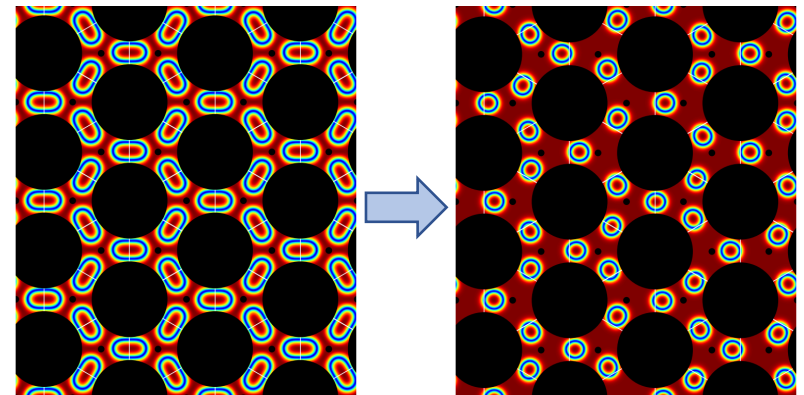
Binary trap

Ice rule





● Type II ● Type III ○ Type V



● Type I ○ Type IV

Validity range

